Physics Goals and Reach of CLEO-C

March 26th, 2001

Laboratory of Nuclear Studies,
Cornell University
and the
CLEO Collaboration

Modify CESR for Operation at E_{cm} = 3-5 GeV

- Luminosity = 1-4 x 10^{32}
- Run Plan
  - 3fb-1 at 3770 ($D\bar{D}$ production)
  - 3fb-1 at 4140 ($D_s\bar{D}_s$ production)
  - 1fb-1 at 3100 (J/ψ production)

About one year each

- Physics Reach of the CLEO-C Program?
  - Data Samples
    - 30M Ψ'' ==> **~6 Million <u>tagged</u> D decays**
    - 1.5M D_sD_s ==> **~0.3 Million <u>tagged</u> D_s**
    - >10^9 J/Ψ ==> **billions of J/ψ's** - UNIQUE
  - Samples are nearly background free

WEAK

QCD

- What can the competition do?
  - Data Samples in 2004
    - BaBar/Belle ~200-400 fb^{-1}
      - » ~500M cc pairs
    - BESII
      - » 50M J/Ψ

Large data set
Large backgrounds

Physics Program Part 1:
Weak Interaction Physics

Physics Targets & Sensitivity

	CLEO-C	BaBar	Current Knowledge
	2-4fb-1	400 fb-1	
f_D |Vcd|	**1.5-2%**	*	n.a.
f_Ds |Vcs|	**≤1%**	**5-10%**	19%
Br(D+ -> $K\pi\pi$)	**1.5%**	**3-5%**	7%
Br(Ds -> $\phi\pi$)	**2-3%**	**5-10%**	25%
Br(D->$\pi l\nu$)	**1.4%**	**3%**	18%
Br(Λc -> p$K\pi$)	**6%**	**5-15%**	26%
A(CP)	**~1%**	**~1%**	3-9%
x'(mix)	**0.01**	**0.01**	0.03

* Still under study

Statistics limited.

Systematics & background limited.

Precision Charm Measurements and the CKM Program

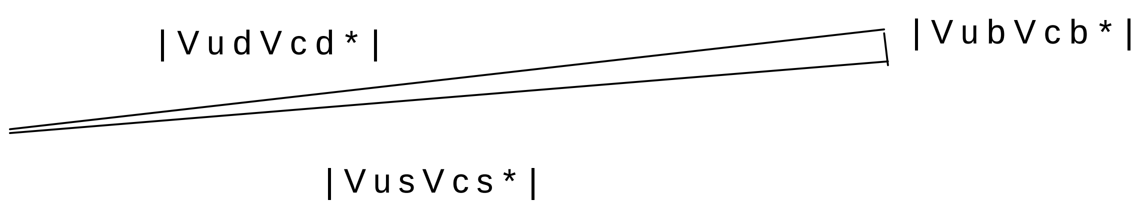
The CKM Matrix:

Vud	Vus	Vub
Vcd	Vcs	Vcb
Vtd	Vts	Vtb

How well do we know these elements from direct measurement (i.e., without imposing Unitarity)?

0.1%	1%	25%
7%	16%	5%
36%	39%	29%

Unitarity may be tested with any pair of rows or columns. Bfactories: first & last columns. CLEO-C: first two rows --



Thus a ~1% measurement of |Vcd| and |Vcs| will allow a check of Unitarity at the 1% level.

The Future of Lattice QCD

(Peter Lepage)

Cornell Workshop on High Precision Lattice QCD, January 2001

– 1% accuracy for dozens of "gold-plated" calculations possible within 2-3 years:
  - Masses, decay constants, semileptonic form factors, and mixing amplitudes for D, D_s, D*, D_s*, B, B_s, B*, B_s*, and corresponding baryons.
  - Masses, leptonic widths, electromagnetic form factors, and mixing amplitudes for any meson in ψ and Υ families below D and B threshold.
  - Masses, decay constants, electroweak form factors, charge radii, magnetic moments, and mixing angles for low-lying light-quark hadrons.

– Uses current (1985-1999) techniques; new types of data (e.g., glueballs) will drive development of new techniques.

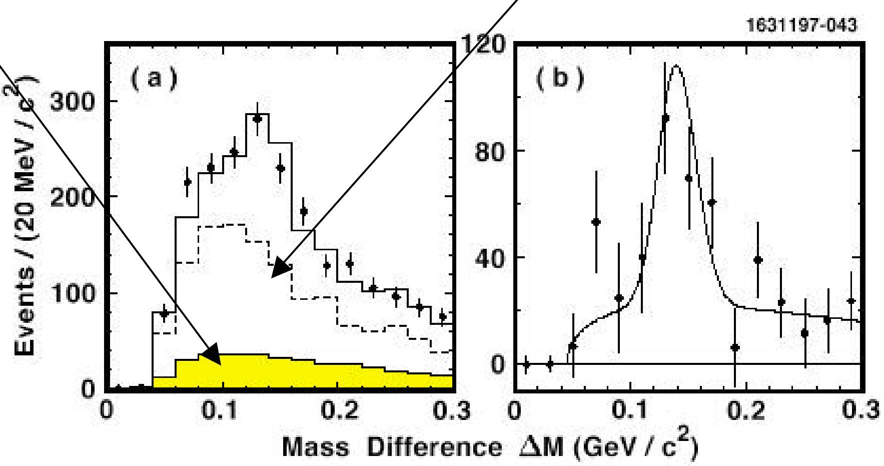
– Progress driven by improved algorithms (theoretical physics), not improved hardware. Future pace will be much faster than pace of hardware evolution.

- One Example: f_{Ds} from $D_s \to \mu\nu$
  - $B(D_s \to \mu\nu)$ **DONE AT Υ(4S)**
    - Search for $D_s^* \to D_s \gamma$, $D_s \to \mu\nu$
      - Depends on “neutrino reconstruction”
      - Backgrounds are LARGE!
    - Precision limited by systematics of background determination **~5-10%**

CLEO signal 4.8fb^{-1}

Excess of μ over e fakes

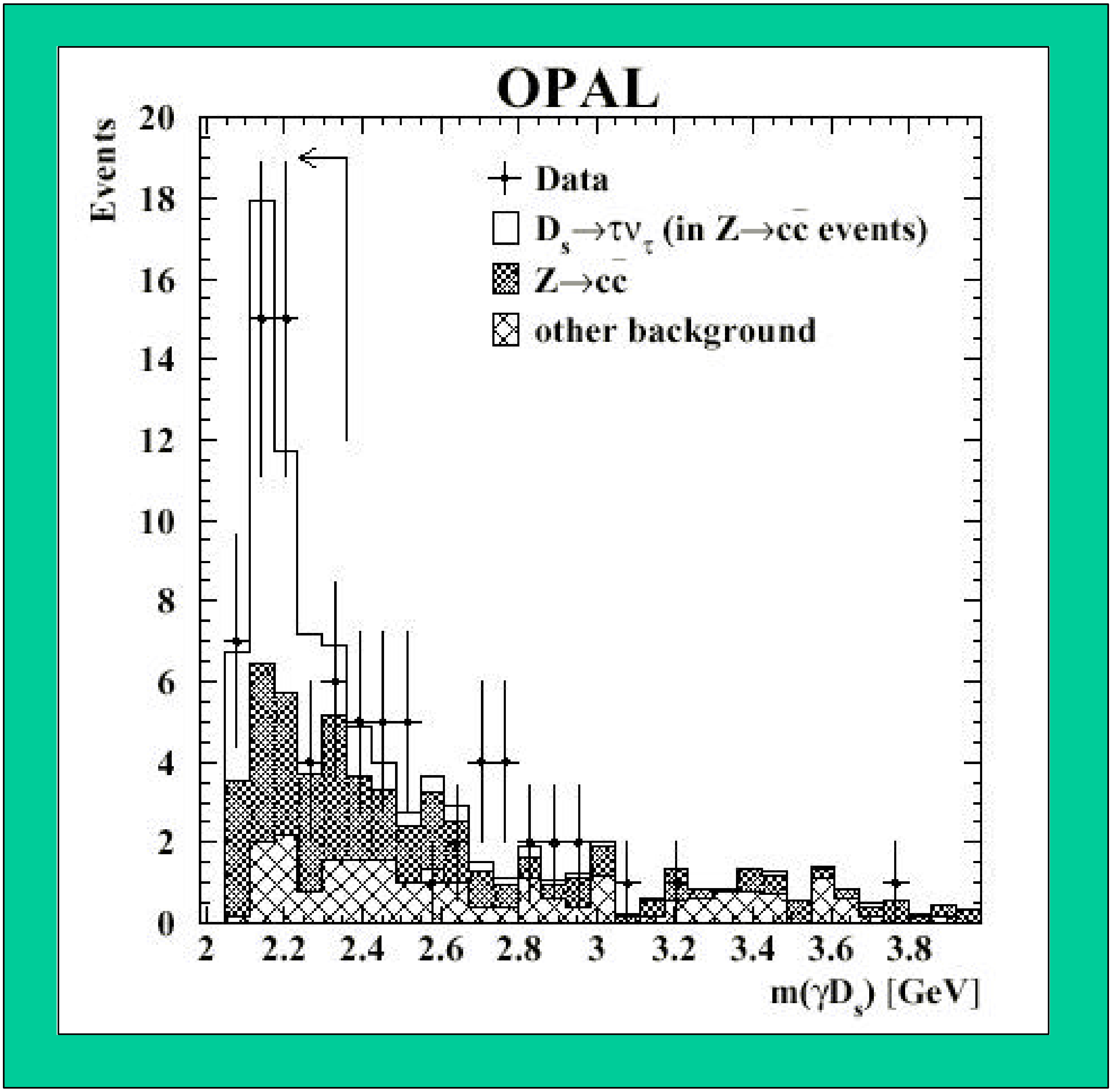
Background measured with electrons



CLEO @ Y(4S)

Determination of f_{Ds} from OPAL (March 2001)

$f_{Ds} = 286 \pm 44 \pm 41$ MeV (21%)

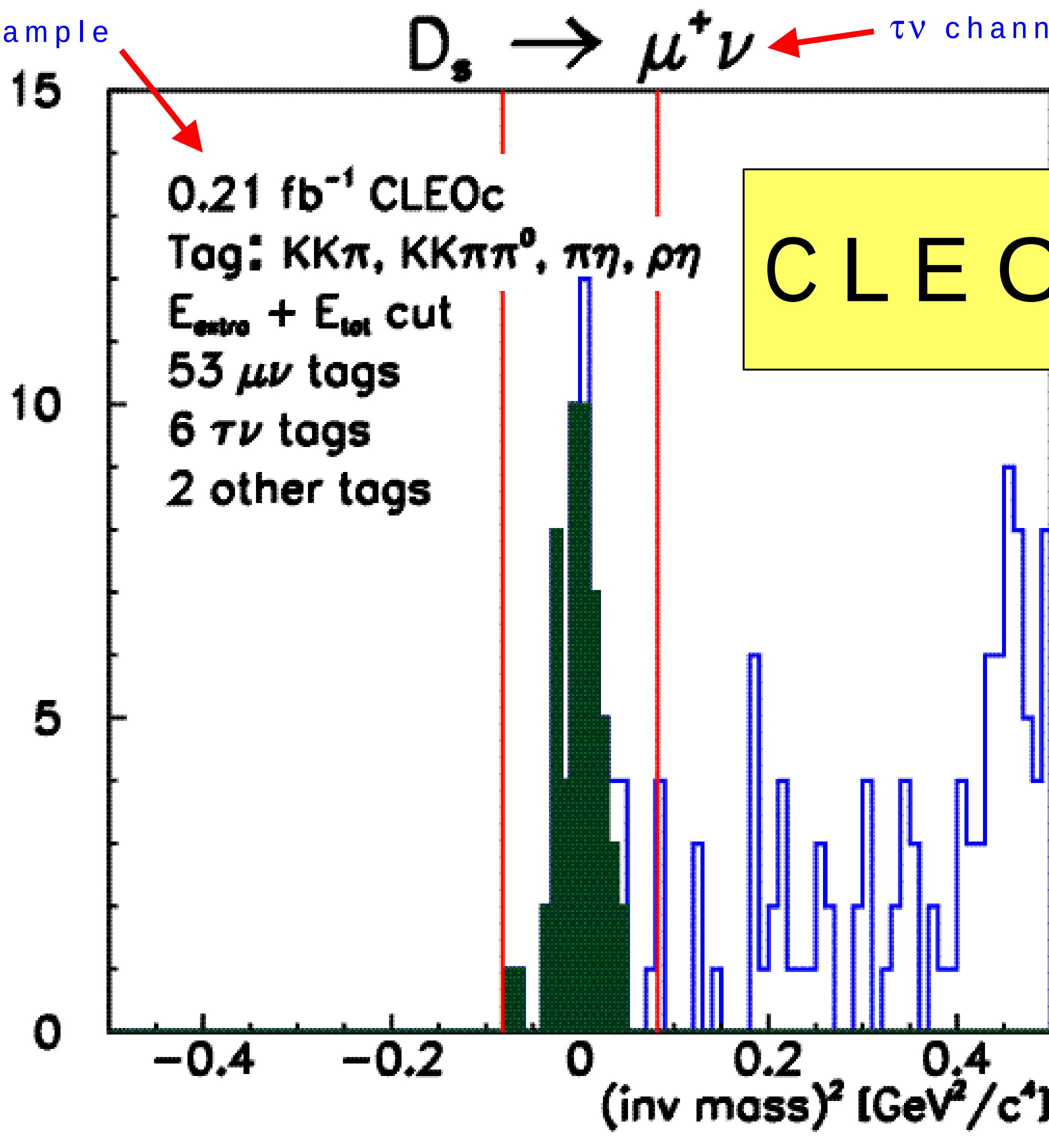


… And the same D_s->$\mu\nu$ done at threshold…

- Take advantage of threshold running
  - Tag D_s by full reconstruction (10% eff)
  - Look opposite for single track
  - Negligible background!
- Precision limited by statistics ~1%

6% of projected
Data Sample

τν channel 4x more



CLEO-C

Summary of CLEO-c Probes of Weak Interaction Physics

Enabling measurements for tests of weak decays

- Precision measurements
  - Absolute charm BR's
  - Semi-Leptonic form factors
  - Stringent calibration/validation of LQCD
- Precision Decay Constants f_D, f_{Ds}
  - Extract Vcs, Vcd to ~1%
  - Precision test of Unitarity
  - Complete the CKM program
- S.L. Decays

Probe essential nature of weak decays

- Searches for new physics
  - D mixing
  - CP Violation in D decay
  - Rare D decays

Look for the unexpected

Low background environment --> qualitative and quantitative advantage

Physics Program Part 2

Low Energy QCD: Grappling with a Nonperturbative World

- Unambiguous predictions of QCD:
  - Glueballs $G=|gg\rangle$ & Hybrids $H=|gq\bar{q}\rangle$
    - Rich spectrum predicted; no definitive assignments to observed bumps
    - Essential verification of QCD to find evidence of these states
    - Essential test of our understanding of strongly coupled theory to calculate their spectra
- The most interesting, challenging, and unique part of QCD is not under control: nonperturbative physics
- Goal of CLEO-C QCD Program:
  - Determine composition for variety of exotica in 1.5-2.5 GeV mass range

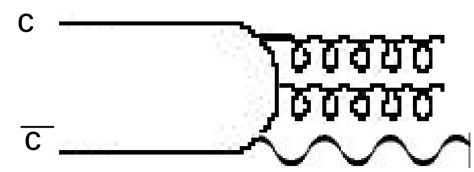
The Challenge of Strongly Coupled Field Theories

- Biggest challenge in theoretical physics
  - Strongly coupled field theories are generic; weak-coupling is a special case.
  - Many communities working on the issues
    - String theorists
      - Calculation of glue ball spectrum
    - Lattice gauge theorists
      - Only fundamental tool for dealing with SC

- How does CLEO-C program fit it?
  - QCD needs detailed, high quality data to drive it forward.
  - Who cares?
    - Near term: B physics! We see hadrons, not quarks.
    - Long term: High energy frontier: strongly coupled sectors above 1 TeV
  - Complete the last known sector of QCD (glueballs, hybrids) with precision data

Example: Search for “Glueballs”

- Strategy Part 1: 1fb^{-1} on J/Ψ
  - Search for states in glue rich environment
    - B(J/Ψ -> γ X) ~ 6%
      - Copious source of color singlet gg pairs
      - $J^{PC}=0^{++},0^{-+},2^{++}$
  - Partial Wave Aanalysis to get Quantum Numbers of observed states
    - Hermetic detector / Low background



- Strategy Part 2: Current 2γ Data - 25fb^{-1}
  - Anti-search in glue-poor environment
    - Eg. e^+e^- -> $e^+e^-\gamma\gamma$ -> e^+e^-X ….
    - Two Photon production favors qq (photon couples to charge)
- Strategy Part 3: 1fb^{-1} on Υ(1S)
  - Compare Γ(J/Ψ -> γX) and Γ(Υ(1S) ->γX)
    - Can confirm existence of states
    - Probe details of wave functions
    - Test conclusions drawn from J/Ψ & $\gamma\gamma$ data

Interaction with Lattice QCD

(Cornell Workshop on High Precision Lattice QCD)

(gpl)

ψ and Υ Physics

- >30 gold-plated (1%) lattice calculations possible within next 2-3 years.
  - Masses, spin fine structure for S, P, D states.
  - Leptonic widths for S-states.
  - Electromagnetic transition form factors for P->S states, S->P states ….
  - S-D mixing.

- Richest, most efficient calibration/ testing ground for lattice techniques.
  - Detailed verification of a major <u>new</u> theoretical technique (cf 1950's).
  - Essential for credibility/viability of high-precision B, D experiments at BaBar, CLEO …
  - Calibrates many different techniques.

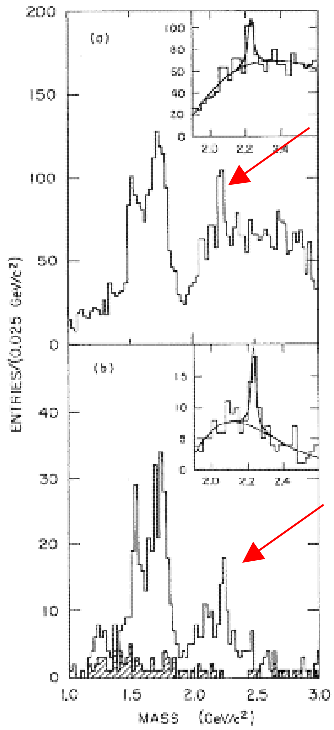
- Essential precursor to heavy-hybrid searches.

Current Status

- Experimental
  - Far from clear!
  - List of "glue ball" suspects
    - $\eta(1400)$ region
    - $f_0(1500)$
    - $f_J(1710)$
    - $\xi(2230)$
  - The situation is complicated and experimental results are contradictory
  - Sorting it out will be challenging!
    - Looks messy now due to <u>insufficient statistics</u>
- Theoretical
  - Lattice: Believable and increasingly precise

Example: the x(2230)

MKIII
1986



BES
1996

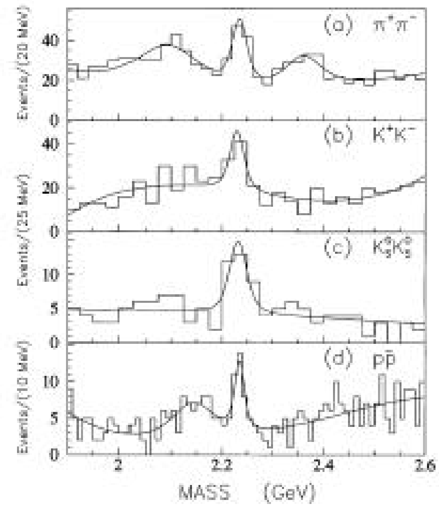
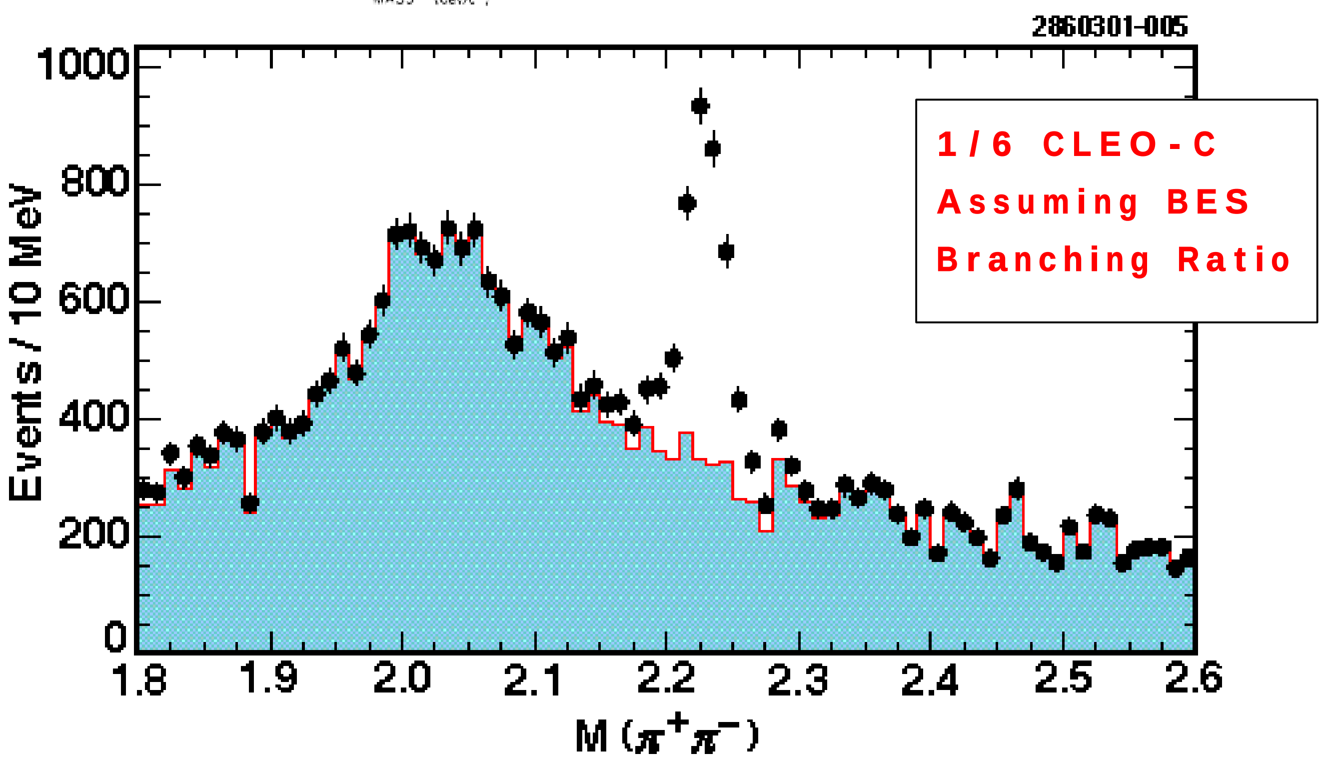


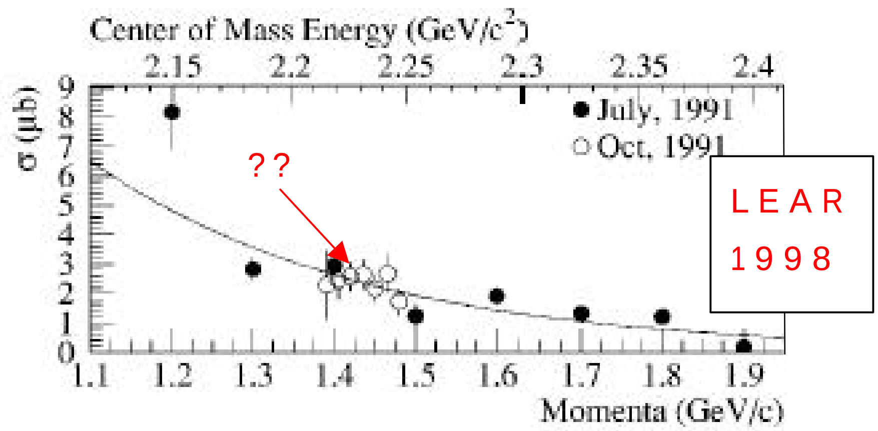
FIG. 2. Fitted invariant mass spectra of (a) $\pi^\pm\pi^\mp$, (b) $K^\pm K^\mp$, (c) $K^0_S K^0_S$, and (d) $p\bar{p}$.

f produced J/ψ, and

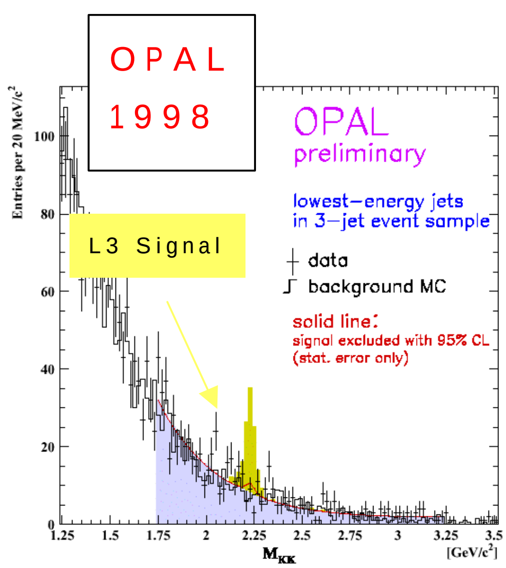


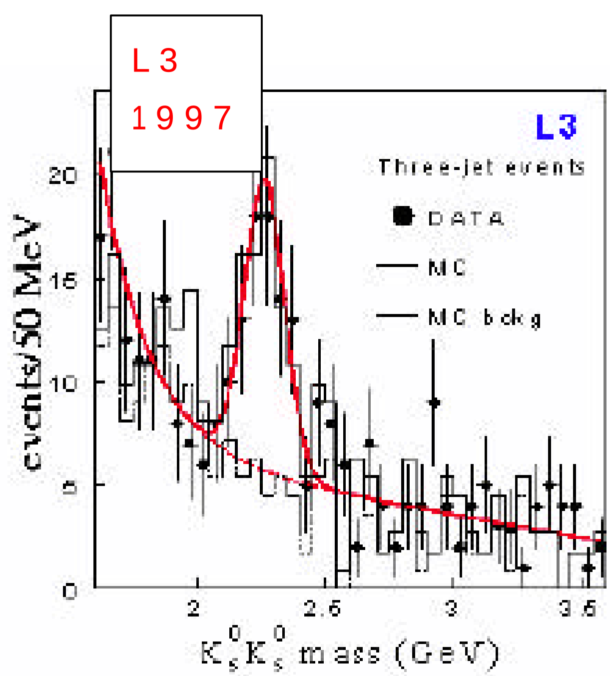
...But the existing measurements are murky...

No evidence in ppbar from LEAR (high statistics!):



Inconsistent reports from OPAL and L3 in 3-jet events:





Comparison with Other Expts

China:

BES II is running now.

BES II --> BES III upgrade

BEPC I --> BEPC II upgrade, ~10^{32} lumi.

being proposed

Physics after 2005 if approval & construction go ahead.

Quantity	BES II	CLEO-C
J/psi yield	50M	> 1000M
dE/dx res.	9%	4.9%
K/pi separation up to	600 MeV	1500 MeV
momentum res. (500Mev)	1.3%	0.5%
Photon resolution (100 Mev)	70 MeV	4 MeV
Photon resolution (1000 Mev)	220 MeV	21 MeV
Minimum Photon Energy	80 MeV	30 MeV
Solid angle for Tracking	80%	94%
Solid angle for Photons	75%	95%

HALL-D at TJNAL:

γp to produce states with exotic Quantum Numbers

Focus on light states with J^{PC} = 0+-, 1+-, …

Complementary to CLEO-C focus on heavy states with J^{PC}=0++, 2++, …

Physics in 2007+ ?

Summary of CLEO-C Program

- Significant/Unique reach in weak physics
  - Precision measurements of decay constants and absolute Br: --> Precision CKM Unitarity tests.
  - Searches for new physics -> CPV, Dmix, rare D decays,...
  - Competes favorably with B-factories
    - Measurements both qualitatively and quantitatively better; in some cases x10 better
  - Complements and bolsters B-factory program
    - CKM tests, Charm BR, LQCD proving ground, HQET

- Significant/Unique reach in QCD
  - >20 times world's data sample
  - Modern detector with significantly better resolution and coverage than BES, MARKIII,...
  - Single experiment: 3-prong attack
  - Clean up problems that have been outstanding in low energy QCD for almost 20 years
  - Lay groundwork for understanding a strongly coupled world.

What about the collaboration?

- The present CLEO collaboration has voted overwhelmingly in favor of the CLEO-C project

116 yes,
30 probable -- depending on funding
9 reluctantly no -- due to retirements etc

  - Important part of the Heavy quark/CKM program
  - New opportunities in the QCD sector
  - Natural fit with future plans (BTeV, LHC,…)

- Seeking new collaborators from the both high energy and medium energy community. Rich new spigot of data.

Workshop on Prospects for CLEO/CESR with 3 < Ecm < 5 GeV

May 5-6-7 (Sat-Mon)

Cornell University

www.lns.cornell.edu/public/CLEO/CLEO-C

- Measurements of charm meson branching fractions and decay constants
- D mixing
- Semileptonic charm decays
- Tau mass and other threshold measurements
- Branching fractions of Λ_c
- CP violation in D decays
- Rare decays of D and D_s mesons
- QCD studies with 10^9 J/ψ decays
- Searches for QCD hybrids and exotics
- Light meson spectroscopy
- Opportunities at the $\psi(2S)$
- Measurements of R
- Physics opportunities in $\gamma\gamma$ collisions

Why *CLEO*? Why *now*?

• We have a first class detector vastly superior to what has been used by other experiments.

• We have a high luminosity machine capable of delivering 100x luminosity of existing machines in this E_{cm} range

• Lattice QCD primed to meet the challenge of precision measurements.

• We have an experienced and well-equipped collaboration ready to act.